PRINCIPLES OF TIME-MEASURING APPARATUS [1]

IV.

Balance Springs.

THE earliest watches were constructed, so far as the escapement and balance were concerned, upon exactly the same plan as the clock from Dover Castle, and in this condition they must have perpetually remained (useless as time-measurers), but for the invention of the balance-spring (sometimes called the pendulum-spring, on account of the uniformity it imparts) by Dr. Hooke.

This spring bears the same relation to the balance which gravity does to the pendulum. Everybody, I presume, knows the form it usually takes in watches; and in chronometers it is coiled up around an imaginary cylinder. This spring (as in the case of the pendulum) absorbs the energy of the impulse, and when the balance has reached the limit of its swing, redelivers to it all it has received. A watch is regulated by shortening or lengthening the balance-spring, which makes it more or less rigid.

Watches and chronometers vary their time to a much greater extent upon any change of temperature than clocks do. For instance, if we regulate a chronometer without any compensating arrangement, with

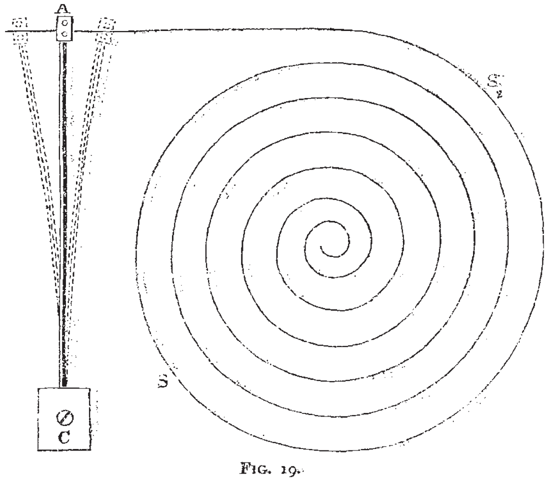

FIG. 19.

a balance-spring of steel, to go right at a temperature of 32 deg., when we raise the temperature to 100 deg. it will lose 6 minutes 25 seconds a day, whereas a clock with an ordinary steel rod pendulum would barely lose 20 seconds for the same change. This great difference is owing to the alteration in elasticity of the balance-spring (the effect really being the same as if, with reference to the pendulum, we could reduce the force of gravity).

Different materials are in this respect differently affected. Whereas a chronometer with a spring of steel will lose 6 minutes 25 seconds a day for 68 deg. rise in temperature, one with a gold spring would lose 8 minutes 4 seconds; a palladium spring would lose 2 minutes 31 seconds; a glass [2] spring would lose 40 seconds. On account of the large amount of compensation required, quite a different plan has to be employed to that made use of in clocks.

Suppose I take two thin strips of brass and steel, and fasten them rigidly together (the best plan is to pour the melted brass upon the steel), what will happen when there is any change of temperature? Imagine the temperature to rise, both expand, but the brass more than the steel, and how it manages this, being rigidly fastened to it, is by bending round the steel into a curve, of which *it* (the brass) is upon the *outside.*

Fig. 19 represents the first form of compensation applied to watches. C A is our compound bar (the steel, shaded black, being nearest the spiral), the extremity of which carries two pins applied to the balance-spring as the ordinary regulator.

When the temperature rises the brass expands and bends round the steel, shortening the balance-spring, and thus compensating for its loss of elasticity due to the rise in temperature. The reverse action takes place when the temperature falls.

The plan adopted now-a-days is the compensation-balance (see Fig. 20). The rims, $R_1 R_2$, are formed of two strips of brass and steel, the brass being upon the outside. When the temperature rises, the brass expands more, and bends in the rims, carrying the weights W towards the axis of motion a sufficient distance to compensate for the loss of time due to the loss of the spring's elasticity.

As you see, the action of the compensation may be readily increased by shifting the weights nearer to the ends of the rims.

Where a chronometer is exposed to very wide ranges of temperature, there is another error (called the secondary

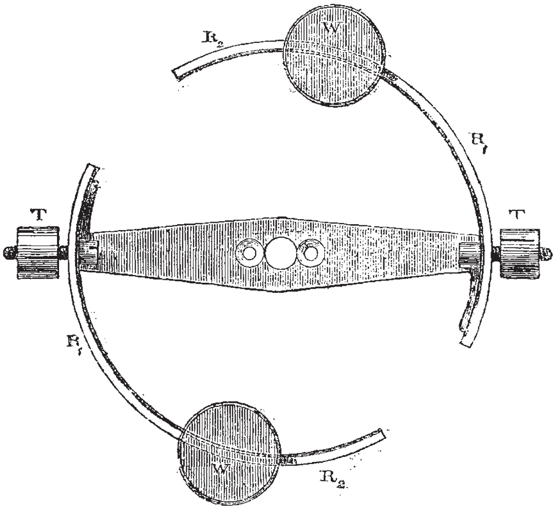

FIG. 20.

error) introduced. If, for example, we take a chronometer with such a balance as just described, and so adjust the compensation-weights that it shall go right at a temperature of 66 deg. and 32 deg., we shall find that when we expose the chronometer to a temperature of 100 deg. it will lose about four seconds a day; and we cannot correct it, for if we advance the compensation-weights along the rims to increase their action in the heat, we shall also increase it in the cold, and then the chronometer will lose in that direction. The best we could do would be so to adjust the weights as to make the chronometer lose two seconds a day in the heat, and two seconds a day in the cold.

The cause of this error is that the time of the swing of a balance depends not directly upon the distance of its weights from the axis of motion, but upon the square of that distance; and it therefore requires a greater amount of motion inwards to produce the same effect as any given motion outwards.

The following is one of the plans adopted for the correction of this error (see Fig. 21):—

F B is a flat bar composed of brass and steel fastened together, the brass being beneath. L L are two loops also formed of brass and steel, the brass being inside. The compensation weights, W W, are mounted upon

[1] Lectures by Mr. H. Dent Gardner, at the Loan Collection, South Kensington. Concluded from vol. xiv. p. 575.
[2] The glass spring was the invention of the late Fredk. Dent.

two rods, R R, fastened upright upon the extremities of the loops.

When the temperature rises, the flat bar bends upwards, and tilts in the loops and the weights at their extremities. But at the same time the loops open a little, and as they are pointed towards the axis of motion, A A, advance the compensation weights a little further in upon their own account. Thus the action of the main bar is increased in the heat. In the cold, the main bar bends downwards, and tilts out the weights, but in this case the loops close, and as they are now pointed away from the axis of motion, by doing so, *bring back* the weights a little. Thus the action of the balance is reduced in the cold. The secondary error is in this manner corrected.

Balance-springs have this very important property, that you are able to isochronise them, that is, so adjust them that the balance shall perform long and short arcs of vibration in the same time. The rule for doing this is simple, though exceedingly difficult of execution upon account of the minuteness of the operation; if the chronometer gains in the short vibrations, you shorten the spring, and if it gains in the long vibrations, you lengthen it. The best plan is to leave it gaining a trifle in the short vibrations, for the reason I pointed out to you when discussing the circular error in pendulums. A chronometer gaining 3 or 4 seconds a day in the short vibrations will also be compensated against changes in atmospheric pressure.

The best watches are always timed in positions. There is of course much more friction when the pivots are rolling upon their sides than when turning upon their ends; gaining in the short vibrations tends to correct variation due to this. In general, timing in positions is a work of the very greatest difficulty, and perfect accuracy can only be obtained when the balance-spring weight of the balance and mainspring are in exact adjustment.

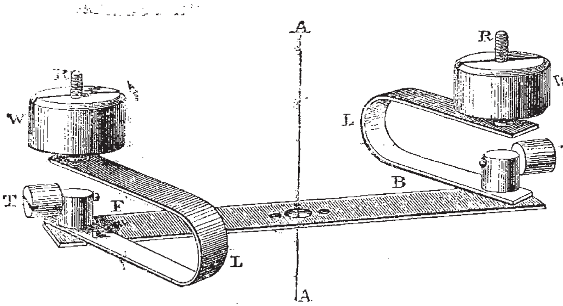

FIG. 21.

A very curious property sometimes exhibited by chronomoters is to gain upon their rates, that is to say, if the average daily rate of the chronometer were during the first month 1 second a day fast, during the second it would be $1\frac{1}{2}$ seconds, and during the third month 2 seconds.

This arises from the balance-spring having been left at too high a temper after hardening. On the other hand, if the temper were left too low the chronometer would lose upon its rate. Glass springs exhibit the tendency to gain upon their rates to a remarkable degree.

Watch Escapements.

It would never do to have watch balances vibrating so small an arc as clock pendulums; the least we can do with is 200°, that is, 100 times as much. If you will remember the various clock escapements described, you will see that not one of them is suitable to fulfil such conditions, and something quite different had to be devised.

The form most generally employed is Mudge's detached lever, which is more in favour to-day than it ever was. P P are the pallets (see Fig. 22) mounted along with a lever, L L, upon a spindle, S. During the greater part of the swing of the balance, the lever and pallets are lying against either of the banking pins, B B. There is a notch, N, in the lever and a pin, I, to correspond upon the disc, R, which moves around along with the balance in the direction shown by the arrow. By-and-by the pin upon the disc will catch the notch in the lever and unlock the escape-wheel, a tooth of which is now being held against the dead face, D, of the pallet; the tooth will immediately slide along the slant, and deliver its impulse, which will be transmitted to the balance through the connection of the pin and disc R. The lever whilst resting against either of the banking pins is held in position by a little "draw" upon the dead faces of the pallets, that is, they are slanted back so that the pressure of the wheel teeth thrusts them away from it. There is also a safety disc, O, underneath the unlocking one, and a safety tongue in the lever, which, in the event of the watch getting a shake prevents its falling over to the opposite side of the balance-spindle to that where the unlocking pin is then situated.

People are continually "improving" this escapement, generally by making some slight alteration in the pins, but the broad principle and details always remain the same, as I have described them to you.

Another form of escapement very much used in foreign watches is the horizontal, invented by the same Graham already referred to; but as it does not possess qualifications for accurate time measurement, I shall not describe it.

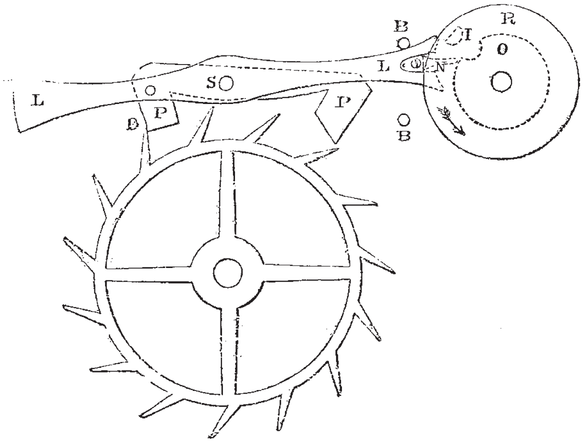

FIG. 22.

Our last escapement is that universally employed in chronometers (see Fig. 23); its original conception is apparently due to Arnold, though it was modified and greatly improved by Earnshaw. S S is the escape-wheel, which is now being held by the detent, D. R_1 R_2 are two discs, the smaller being situated in the plane of the detent, and the larger in the plane of the escape-wheel; both of them move upon the same spindle with the balance. The balance is now turning in the direction of the arrow; by-and-by the finger, P_2, upon the smaller roller will come round and lift away the detent, and the wheel will be free. The tooth, T, will then drop upon the impulse pallet, P_1, and deliver impulse to the balance. Meanwhile, the finger, P_2, gets clear of the detent, which it allows to fall just in time to receive the succeeding tooth of the escape-wheel.

The balance now passes on to the limit of its excursion, and returns; but in returning the finger does not interfere with the detent for the detent, D, is actually too short to reach it. Just now the finger really unlocked the detent by means of the little spring, Y Y, which is fastened some distance down the detent, the little spring being supported by the horn or extremity of the detent; but when the finger returns, it merely lifts out the spring, as there is upon this side no horn or extremity to support it.

Distribution of Time by Electricity—Chronographs.

To those acquainted with the difficulties in the way of communicating a uniform impulse to the pendulum through the medium of a train of wheel-work, it has, always been a favourite idea directly to maintain the swing of the pendulum by means of an electric current, but, unfortunately, the thing has not hitherto proved feasible; apparently it must be taken for granted that the action of an electric current cannot be *constantly* maintained.

But although electricity is of little service for keeping clocks going, it has been very successfully employed in controlling them. It is, of course, very much more economical to have inferior clocks than good ones, and what is done in this case is to use one good clock for the purpose of controlling a quantity of bad ones. The nature of the apparatus is in general this: our first good clock and all the others are placed in the circuit of a galvanic battery, and what our first good clock does is to close the circuit and transmit a current at every beat of its pendulum. The passage of an electric current around a coil of copper wire (as you no doubt know) converts it for so long as it passes into a magnet, and this current so transmitted by the clock is employed for such a purpose, and the magnets so formed are constructed to operate upon the pendulums of the controlled clocks and accelerate them if they are

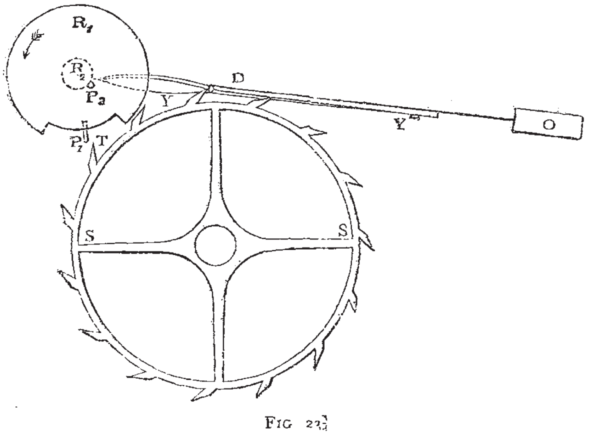

Fig 23

lagging, or resist them if they should be moving too quickly.

Electricity is also employed for the purpose of correcting the time of a clock, say once a day. In this case the clock which is to be corrected is kept at a slight gaining rate. Upon the axis of its escape-wheel is a little finger which revolves with it. At a few seconds before, say 1 o'clock, the controlling clock, by the transmission of a current, brings down an arm in front of the finger and stops the controlled clock for just so many seconds as it is in advance of the controlling clock; at 1 o'clock the arm is raised again, and the controlled and controlling clock start off approximately together.

Such a controlling clock as is used to transmit a current, say once a day, is also employed for the purpose of dropping time-balls and discharging guns. The time-ball itself is generally composed of wicker-work covered with canvas, and is wound up by hand to its position a few minutes before the transmission of the current, and held by a hook or detent. Upon the arrival of the current the detent (by what arrangement it is unnecessary to describe) is withdrawn, and the time-ball falls.

To discharge a time-gun, the current usually passes through a very fine platinum wire, which it makes red-hot. Both with time-balls and guns, and wherever it has heavy work to perform, the current from the clock is employed to close another and much more powerful circuit, the latter being that which operates upon the mechanism.

Instruments employed for the purpose of registering the passage of short intervals of time are called chronographs. These in the main consist of a cylinder covered around with paper revolving at a uniform rate. The rotation of those employed in observatories is generally controlled by what is called a conical pendulum, that is, a pendulum swinging round in the surface of a cone. Such pendulums are much more sensitive to any slight change in the pressure of the clock-train than ordinary oscillating pendulums, and require to be controlled by special apparatus. The pendulum used at Greenwich is so contrived, that when it endeavours to move faster (in doing so, of course swinging out further) it dips little spades into an annular trough of glycerine, and its velocity by this means is checked.

The operation of the apparatus is the following:—A pin upon the pendulum of the normal sidereal clock presses two weak springs together at every vibration, and so transmits a current. This current, by making an electro-magnet, brings down a striker upon the paper of the revolving cylinder. By an arrangement similar to a screw-cutting lathe, the frame carrying this striker just as the cylinder rotates, travels alongside of it, and the clock-beats are consequently indicated upon the cylinder in the form of a spiral of successive pricks. The mechanism attached to the clock is arranged so as to pass no current at the termination of each minute (the sixtieth second), and consequently a blank is left upon the cylinder, by which anybody can tell when the minute happened. Upon the same frame alongside the first striker is a second, which can be brought down by the observer at any one of the instruments, by touching a button at his side. His observation is consequently registered upon the barrel alongside the clock-beat, and you have no difficulty in determining its precise time of occurrence to the tenth or one-hundredth of a second.

Similar instruments are employed for determining the velocity of projectiles, but in these the cylinder travels at a much higher velocity, and other means of controlling it are made use of.

THE ARCTIC EXPEDITION

IT will of course be some time ere all the results obtained by the Expedition which has just returned from its year's sojourn on the edge of the ice-blocked Polar Sea can be presented to the public. Enough, however, is known to lead us to believe that abundant additions of the highest importance to our knowledge of the physics and natural history of the Arctic Regions have been made; and meantime we are able to exhibit in a map the main additions which have been made to Arctic geography.

The *Alert* and *Discovery*, under Captains Nares and Stephenson, left England in May, 1875. Godhavn was left on July 15, and all seems to have gone well till July 30, when, after leaving Port Foulke, the ice was met off Cape Sabine, 78° 41′ N., from which point the ships had a constant struggle with the pack to the north end of Robeson Channel. So close was the ice that on every occasion the water channel by which the ships advanced very soon closed behind them, rendering it as difficult to return as to proceed north. On August 25, after many hairbreadth escapes, a well-sheltered harbour was reached on the west side of Hall's Basin, north of Lady Franklin Sound, in lat. 81° 44′ N. Here the *Discovery* was secured for the winter, a few miles north of Polaris Bay, which was in sight on the opposite side of the channel.

The *Alert*, pushing onward, rounded the north-east point of "Grant Land," but instead of finding a continuous coast-line leading 100 miles further towards the north, as everyone had expected, found herself on the border of what was evidently a very extensive sea, with